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MITIGATION PLAN – INCREMENTAL COST ANALYSIS - Appendix F

For the

Miami Harbor Navigation Study General Reevaluation Report

Miami-Dade County, Florida - 010140

US Army Corps of Engineers

Jacksonville District

South Atlantic Division

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Article I. Seagrass Mitigation

Section 1.01 Introduction

Restoring seagrass beds, if successful, can be an appropriate mitigation strategy due to its high ecological value and declining abundance. Seagrass restoration adds habitat value to unvegetated sand or mud substrates. The addition of seagrass beds increases the productivity and diversity of the unvegetated bottom, which can directly compensate for the historic loss in productivity and diversity.

Fonseca et al. (1996a, 1996b) found that within three years, restored seagrass beds (*H. wrightii*) planted on 0.5-m centers reach the same areal density and support animal densities, number of taxa, and species composition equivalent to natural beds. Some restored seagrass beds support invertebrate populations that are as or more abundant than those in natural grassbeds (Bell et al. 1993). Restored seagrass beds appear to be as suitable as natural seagrass beds for juvenile and small adult fish (Brown-Peterson et al. 1993).

Restored seagrass beds support animal densities similar to natural seagrass beds when shoot density is only one-third that of a natural seagrass bed (Fonseca et al. 1996). Thus, the habitat value of a restored seagrass bed is maximized relatively quickly, prior to the restored bed reaching the same vegetative density as a natural seagrass bed. In addition to providing habitat itself, seagrass beds increase the productivity of adjacent habitats. Irandi and Crawford (1997) found that the presence of seagrass beds adjacent to tidal marshes increased the abundance and growth rates of fish in the tidal marsh.

Research has identified that seagrass beds are more diverse and productive than unvegetated substrate. Average fish densities in natural seagrass beds were ten times greater than those on unvegetated areas (~20 individuals/m^2 versus 1.74 individuals/m^2). Shrimp densities in natural shoal grass beds averaged 151 individuals/m^2 compared to 3.02 individuals/m^2 in unvegetated areas. Crab densities in natural seagrass beds were 20 to 50 individuals/m^2 compared to an average of 1.91 individuals/m^2 on unvegetated areas (Fonseca et al. 1996). Within 1.5 years of planting, restored seagrass beds support shrimp, fish, and crab densities similar to natural seagrass beds (Fonseca et al. 1996). Thus, restored seagrass beds can increase the density of shrimp, fish, and crabs by 10 to 50 times compared to unvegetated substrates.

Although research has identified that seagrass beds are more diverse and productive than unvegetated substrates, relatively few studies compare secondary productivity between seagrass beds and other habitats. Heck et al. (1995) determined that eelgrass beds in the northeastern United States had macroinvertebrate production 5 to 15 times higher than adjacent unvegetated habitats. At least a similar increase in productivity is expected for *H. wrightii* and *T. testudium*, which have a higher primary productivity than eelgrass. Also, a similar increase in abundance, diversity, and productivity of fish species may also be expected.

Restoration of seagrass communities, while still considered experimental and not highly successful by resource agencies, can enhance habitat heterogeneity and the diversity of invertebrate and fish communities, if carefully implemented. The recent treatise on seagrass restoration entitled "Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters" by Fonseca et al. (1998) discusses the benefits and risks associated with seagrass restoration. Given the documented success of more recent efforts to restore seagrass communities, including those in South Florida, restoration is quickly becoming a proven resource management tool in some areas where conditions are appropriate.

(a) Impacted Acreage and Associated Mitigation Requirements

Impacted seagrass acreage for the recommended plan is 6.3. Mitigation will be performed at a 1:1 ratio; however, the hole we propose to fill has a surface area of 18.6 acres (see *Potential Mitigation Sites*, below). To ensure success of the mitigation for the 6.3 acres of seagrass impacts, the Corps must fill the entire 18.6-acre hole.

(b) Potential Mitigation Sites

(i) Type of Mitigation

Over 25 mitigation options ranging from significant tidal and mangrove habitat restoration in south Biscayne Bay to restoring seagrass habitat in north Biscayne Bay were considered for mitigating seagrass impacts. Based on detailed analysis, the requirement to perform in-kind mitigation if possible, and significant agency coordination, restoring seagrass habitat in north Biscayne Bay was the preferred option.

(ii) Options for In-Kind Mitigation

Three in-kind mitigation options were explored.

1) Prop Scars

The first option was to fill "prop scars" in the Bill Sadowski Critical Wildlife Area (BSCWA) to the south of the port. This option would restore seagrass to areas where boat groundings or propeller scars have impacted the seagrass. There is not an estimate of area requiring restoration, and the Corps is concerned that the restoration technique will be very labor intensive. This area is very shallow in depth and is also a "no boat" area. It is also a high use area for the endangered Florida manatee, which may limit when and how the construction could be conducted.

2) Dade County Marine Stadium Site

The second seagrass restoration site is at the Dade County Marine Stadium on Virginia Key, located to the south of the port and the previously mentioned BSCWA. It would result in 19.55 acres being restored – however, the project is not solely for mitigation of seagrasses – but is a combination of seagrasses, mangroves and low marsh. The likelihood of success associated with this proposal was high for marsh restoration and moderate for seagrasses. It is unknown what proportion of the available 19.55 acres is available for seagrasses, and the remaining mitigation would be out of kind.

3) Dredge Holes in North Biscayne Bay

The third and final option for a seagrass mitigation site is dredge holes found in North Biscayne Bay. The Corps was referred to a report from 1989 that was prepared by Miami-Dade County Department of Environmental Resources Management (DERM). This report identified "eight holes" in Biscayne Bay north of the Julia Tuttle causeway. There was very little detailed data about the holes included in the report (surface area and depth). The detailed information would be necessary to determine the most effective mitigation plan. In June 2002, members of the Corps and their contractor performed a survey of the area and determined that the eight holes are actually one very large hole, created when the causeway was constructed. On the northern edge of the main hole (which is more than 400 acres in size) a smaller, 18.6-acre hole was discovered that is 85% contained by the surrounding seagrass meadow. This hole is the smallest existing dredge hole site in the area. In this manner, evaluation of the eight borrow areas resulted in the selection of one site that will provide approximately 18.6-acres.

To ensure success of the needed mitigation, the entire 18.6-acre area must be filled. The additional acreage provided would be banked for future Port use. A table of the different mitigation options considered by the Corps in developing the mitigation plan is included in the mitigation plan, Appendix J of the DEIS.

Section 1.02 Alternative Seagrass Mitigation Plans

(a) Placement Method

Two alternatives for placement of the seagrass were considered: planting the seagrass and allowing the seagrass to naturally recolonize.

(i) Plant

Planting of the proposed 18.6-acre mitigation site is expected to follow a pattern demonstrated by a three-acre restoration site in North Biscayne Bay that was prepared by Miami-Dade County DERM. Restoration of three-acre borrow area in North Biscayne Bay was completed in the late 1990s. Although no monitoring has been done by DERM since planting of the site, a visual inspection by an agency team in 2002 revealed that seagrass occurs throughout the site and was dominated by *H. wrightii* and *T. testudinum.* Discussions with DERM staff indicate the old borrow area was filled with rubble and sand and planting units of both *H. wrightii* and *T. testudinum* installed. Based on this evidence of success, it is agreed that seagrass restoration in deep dredge holes was a viable option for mitigating seagrass loss in Biscayne Bay.

(ii) Recolonize

Another example of successful seagrass restoration is the Miami-Dade sewage cross-bay force main installed by the Miami-Dade Water and Sewer Authority Department in the mid-1990s. The project required trenching of over one mile of Miami Harbor baybottom for pipeline installation, including excavation of 1.80 acres of seagrass beds. Once the pipeline was installed the 22-foot wide trench path was refilled and allowed to recruit with seagrasses. Recruitment had begun within one-year and after two years seagrasses and macroalgaes covered the trench pathway so that it was no longer visible on aerial photography.

(b) Construction Method

Three construction methods for containing the material within the boundaries of the hole were considered: use of sheet pile, use of rock, and use of a combination of sheet pile and rock.

(i) Sheet Pile

Cantilever sheet pile driven or jetted into the sandy bottom material around the borrow site to provide containment would only receive tentative support at the end driven into the bottom material. Additional tiebacks or other methods of lateral support would be required which complicate the construction method before fill material could be added. Dense areas of seagrass surround the borrow site on three sides leaving access for construction equipment from only one side. Construction of the cantilever sheet pile requires careful sequencing to allow shallow draft construction barges and cranes room to exit the borrow site from the one available entry area that has sufficient depths. Filling of the construction site also requires careful sequencing so as to not box-in the construction equipment or limit its access to the borrow site. Construction of the cantilever sheet pile containment system with lateral support and filling of the site would have to occur concurrently from one end or the borrow site and work back to the available access corridor before completion or closing of the access corridor could occur.

(ii) Rock

Rock from the blasting and dredging of the Lummus Island (Fisherman's) channel about six miles away provides a good source of fill material for the borrow site. Transportation of rock material from the dredging project along the Intracoastal Waterway to the borrow site requires the use of small shallow draft barges. A crane barge will transfer rock material from the shallow draft barges for placement in the borrow site. Rock placement will occur to within two feet of the optimum level for seagrass development as shown on plate B-17 of Engineering Appendix B. The crane barge will place a 2-foot sand cap on the rock to complete filling of the borrow site to match the depth of the adjacent seagrass areas. Rock provides a stable foundation for capping and seagrass development. Filling of the borrow site with rock followed by a sand cap would occur sequentially from one end of the borrow site and work back to the available access corridor. Sand material for capping would come from the confined upland disposal site on Virginia Key by small shallow draft barge.

(iii) Combination Sheet Pile and Rock

Combining sheet pile with rock involves use of elements from both of the above methods. Driving or jetting the sheet pile into the sandy bottom material would occur as described above under the sheet pile discussion. Rock material would be used to replace the tieback or lateral restrain system required by the sheet pile method. The construction sequence would also be similar to the sheet pile method.

(c) Alternative Plans

The combination of the two placement methods and the three construction methods leads to six alternative seagrass mitigation plans, as shown in Table 1.

Table 1: Alternative Seagrass Mitigation Plans

	Seagrass Placement Method	
Construction Method	*Plant*	*Recolonize*
Sheet Pile	Seagrass Mitigation Alternative 1	Seagrass Mitigation Alternative 2
Rock	Seagrass Mitigation Alternative 3	Seagrass Mitigation Alternative 4
Rock and Sheet Pile	Seagrass Mitigation Alternative 5	Seagrass Mitigation Alternative 6

Section 1.03 Expected Costs of Alternative Seagrass Mitigation Plans

(a) Seagrass Mitigation Cost Components

Cost components for seagrass mitigation are shown in Table 2.

Table 2: Estimated Costs of Seagrass Mitigation Components

Expense	Cost/Project	AAE Cost/Project
Sheet Pile	$1,119,418	$69,785
Rock	$1,089,418	$67,914
Combination	$1,104,418	$68,849
Plant	$837,000	$52,179
Recolonize	$38,415	$2,395

(b) Initial Cost

(i) Construction of Site Cost

Estimated site construction costs vary according to the method employed to contain the material in the hole. See Table 2 for the estimated costs associated with the use of sheet pile, rock, and a combination of sheet pile and rock.

(ii) Initial Planting Cost

The estimated cost to plant seagrass is $45,000 per acre, or $837,000 for the entire 18.6-acre site, as shown in Table 2. Planting costs are only included as initial costs for Alternative Seagrass Mitigation Plans 1, 3, and 5. Initial costs for Alternative Seagrass Mitigation Plans 2, 4, and 6 do not include planting costs because these plans call for allowing natural colonization to occur.

(c) Chance of Success

The chance of successful recolonization of the seagrass in Alternative Seagrass Mitigation Plans 2, 4, and 6 is 95 percent, as shown in Table 3.

(d) Secondary Cost

Secondary costs are incurred under Seagrass Mitigation Alternatives 2, 4, and 6 if recolonization does not occur within two years and planting is performed as a result.

(i) Secondary Planting Cost

In the event recolonization does not occur after two years, there would be an additional cost to plant the site at that time.

(ii) Discounted Planting Cost

The secondary cost is discounted from t=2 years to the base year to account for its value at that time.

(e) Estimated Expected Cost of Each Seagrass Mitigation Alternative

Table 3 displays the expected cost of each seagrass mitigation alternative. The expected cost equals the initial cost, plus, if applicable, the discounted secondary cost multiplied by the probability of the secondary cost occurring.

Table 3: Estimated Expected Cost of Seagrass Mitigation by Seagrass Mitigation Alternative Plan

Seagrass Mitigation Alternative	Initial Cost	% Chance Initial Success	Secondary Cost	Discounted Secondary Cost	Expected Secondary Cost	Expected Total Cost
1	$1,956,418	99%	n/a	n/a	n/a	$1,956,418
2	$1,119,418	95%	$837,000	$768,308	$38,415	$1,157,833
3	$1,926,418	99%	n/a	n/a	n/a	$1,926,418
4	$1,089,418	95%	$837,000	$768,308	$38,415	$1,127,833
5	$1,941,418	99%	n/a	n/a	n/a	$1,941,418
6	$1,104,418	95%	$837,000	$768,308	$38,415	$1,142,833

Section 1.04 Seagrass Mitigation Benefits

(a) Coverage

Coverage for seagrass is defined by areal coverage – how much area of the substrate is covered by all of the individuals of a selected species within a defined area.

(i) Plant

Coverage of planted areas would be 100% over the mitigation site right after construction was complete on .5m centers using transplanted species of seagrasses from nearby donor beds to the restoration site. Based on other seagrass restoration sites located in Northern Biscayne Bay, we expect good success with high survivability of all species planted.

(ii) Recolonize

Natural recolonization or recruitment from seagrass beds surrounding the mitigation site is expected to occur rather rapidly. Seagrasses in South Florida demonstrate a sequential hierarchy as they colonize new substrates. It is anticipated that ambient depths will range from -2 feet to -6 feet MSL in the restored areas following restoration and that seagrass recruitment will occur rapidly by *H. wrightii* and *H. decipiens,* both of which likely occur within the shallow flats adjacent to the proposed site. Other species including *T. testudinum* and *S. filiforme* will also colonize the site, but generally only after occupation by the early colonizing species previously cited.

(b) Density

Density of seagrass is defined as the number of individual seagrass shoots of a selected species within a defined area.

(i) Plant

Restored seagrass beds support animal densities similar to natural seagrass beds when shoot density is only one-third that of a natural seagrass bed (Fonseca et al. 1996). Thus, the habitat value of a restored seagrass bed is maximized relatively quickly, prior to the restored bed reaching the same vegetative density as a natural seagrass bed. Since planting will likely occur on .5m centers we can expect the density of each species to be low in the first year and increase as the plant shoots mature and grow.

(ii) Recolonize

Density of naturally recolonized or recruited beds onto the new substrate will likely be higher on the edges of the project site and lower in the middle during the first year post construction – filling from the outside of the project boundaries in toward the middle. We expect that the dominant grass in the area will colonize the site only after pioneering grass species previously discussed colonizes it.

(c) Total Expected Acreage by Half Year

Total expected seagrass acreage for each half year of the project is calculated using the expected density and coverage for that time period. By the end of year two of the project, coverage and density are at their highest potential level regardless of the placement method employed.

(d) Average Annual Equivalent (AAE) Acreage

AAE acreage refers to the average yearly acreage of seagrass expected to exist over the fifty years of the project. AAE acreages for the plant and recolonize options are calculated from the information shown in Table 4. Although after year 2 of the project the acreage is equal for both placement options, AAE acreage is higher for the alternatives that employ planting as a placement method because of the higher acreage experienced in the first two years of the project.

Table 4: AAE Seagrass Benefits by Placement Method

Plant				
Year	0.5	1	1.5	2-50
Coverage	100%	100%	100%	100%
Density	20%	65%	85%	90%
Expected Acreage	3.7	12.1	15.8	16.7
AAE Acreage - Plant	16.39			
Recolonize				
Year	0.5	1	1.5	2-50
Coverage	20%	40%	70%	100%
Density	65%	70%	85%	90%
Expected Acreage	2.4	5.2	11.1	16.7
AAE Acreage - Recolonize	16.26			

Section 1.05 Comparing Seagrass Mitigation Plans

(a) AAE Cost per AAE Acre

Base year (discounted) costs of the alternative mitigation plans are annualized to produce an AAE cost for each plan. Dividing the AAE cost of a plan by its AAE acreage provides its AAE Cost/Acre benefits (see Table 5).

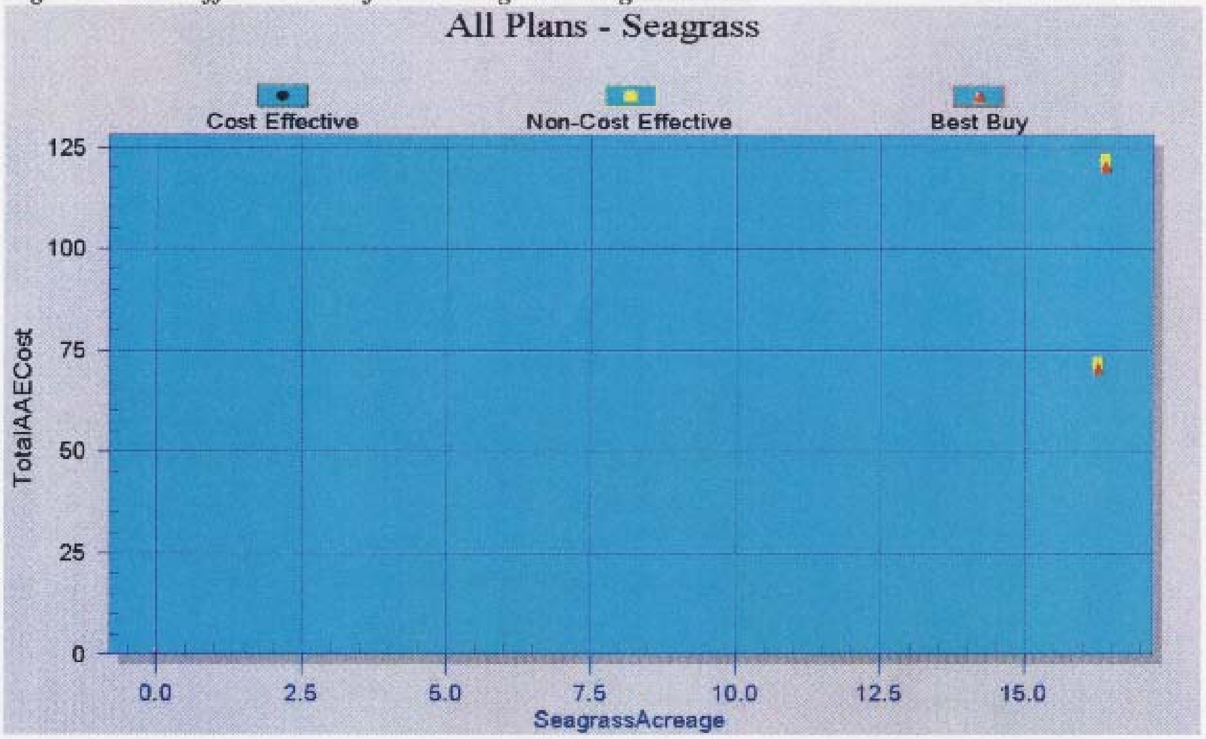
Table 5: AAE Cost per Acre of Seagrass Mitigation by Seagrass Mitigation Alternative Plan

Seagrass Mitigation Alternative	AAE Cost of Mitigation	AAE Benefits of Mitigation (acres)	AAE Cost/Acre
1	$121,963	16.39	$7,443
2	$72,179	16.26	$4,440
3	$120,093	16.39	$7,329
4	$70,309	16.26	$4,325
5	$121,028	16.39	$7,386
6	$71,244	16.26	$4,382

(b) Cost-Effective Seagrass Mitigation Plans

Alternative plans are first compared by identifying cost-effective plans. Cost-effective plans are those that provide a given acreage for the lowest cost. Table 5 shows that Seagrass Mitigation Alternatives 3 and 4 both provide a particular quantity of mitigation at the lowest price; therefore, Alternatives 3 and 4 are cost-effective seagrass mitigation plans. This information can be seen graphically in Figure 1.

Figure 1: Cost Effectiveness of Each Seagrass Mitigation Plan



(c) Incremental Seagrass Mitigation Costs and Acreage

Cost-effective mitigation plans are compared to each other by calculating the marginal costs of increasing the quantity of mitigation by choosing increasingly more expensive cost-effective plans with greater output. Table 6 shows the marginal costs and acreages of both cost-effective seagrass mitigation plans.

Table 6: Incremental Costs of Cost-Effective Seagrass Mitigation Plans

Cost-Effective Plan	Incremental AAE Cost	Incremental Acreage
4	$70,309	16.26
3	$49,784	0.13

(d) Recommended Seagrass Mitigation Plan

From the figures in Table 6 the cost per acre of the extra .13 acres of mitigation achieved through Plan 3 can be calculated as $382,952 ($49,784/.13 = $382,952), compared to $4,325 ($70,309/16.26 = $4,325) per acre for the initial 16.26 acres that are achieved with Plan 4.

Figure 2 compares the two plans' incremental costs per acre graphically and demonstrates the substantial expense of the potential .13 extra acres. This unreasonably excessive expense eliminates Plan 3, leaving Plan 4 as the Recommended Seagrass Mitigation Plan.

Figure 2: Comparison of Cost-Effective Seagrass Mitigation Plans

(e) Sensitivity Analysis

The sensitivity of the outcome of the evaluation and comparison of the six alternative seagrass mitigation plans to the estimate of the initial chance of success when employing the recolonization method is measured through the use of a sensitivity analysis. For the sensitivity analysis, the chance of successful recolonization is assumed to be 50% rather than 95%. This assumption leads to the same recommended seagrass mitigation plan, based on a marginal cost of $191,449 per acre for the extra .13 acres provided by Plan 3, compared to $5,782 per acre for the 16.26 acres provided by Plan 4.

Section 1.06 Estimation of Seagrass Mitigation Costs for Alternative Project Plans

(a) Incremental Seagrass Mitigation Costs by Project Increment

Table 7 displays the estimated seagrass mitigation cost by project increment (see Economics Appendix and Main Report for a discussion of project increments and alternative project plans). Seagrass mitigation costs are assigned to project increments according to the amount of seagrass impacted by the inclusion of that increment. Both widening increments create distinct impacts and the first deepening increment (43 feet) creates additional distinct impacts.

Deepening the channel creates additional impacts because for the two widening increments the existing channel is left undisturbed. As long as deepening occurs in non-rock (sand) material, deepening widens the channels due to the increased volume of the side slopes. There is no mitigation associated with the remaining channel depths because when the non-rock material (sand) ends and rock begins, the side slopes in the rock material increase to almost vertical as the depth increases. Note: Costs shown in Table 7 do not include the potential cost to plant in the event of failure of the recolonization method; rather, the costs represent planned construction costs congruent with the MCACES cost estimate.

Table 7: Incremental Seagrass Mitigation Costs

Increment	Seagrass Mitigation Cost
1C Widen Entrance Channel, 2A Widener between Buoys 13 and 15, 5A Widen Fishermans Channel	$851,958
3B Extend Fisher Island Turning Basin	$13,741
Deepen System from 42 Feet to 43 Feet	$223,718
Deepen System from 43 Feet to 44 Feet	$0
Deepen System from 44 Feet to 45 Feet	$0
Deepen System from 45 Feet to 46 Feet	$0
Deepen System from 46 Feet to 47 Feet	$0
Deepen System from 47 Feet to 48 Feet	$0
Deepen System from 48 Feet to 49 Feet	$0
Deepen System from 49 Feet to 50 Feet	$0

(b) Seagrass Mitigation Costs by Alternative Plan

Table 8 displays the total estimated seagrass mitigation costs for each alternative project plan. Note: Costs shown in Table 8 do not include the potential cost to plant in the event of failure of the recolonization method; rather, the costs represent planned construction costs congruent with the MCACES cost estimate.

Table 8: Seagrass Mitigation Costs by Alternative Project Plan

Project	Seagrass Mitigation Cost
Alternative Plan A: No Action	$0
Alternative Plan B: 1C Widen Entrance Channel, 2A Widener between Buoys 13 and 15, 5A Widen Fishermans Channel	$851,958
Alternative Plan C: 3B Extend Fisher Island Turning Basin	$13,741
Alternative Plan D: 1C Widen Entrance Channel, 2A Widener between Buoys 13 and 15, 5A Widen Fishermans Channel and 3B Extend Fisher Island Turning Basin	$865,699
Alternative Plan H: 1C Widen Entrance Channel, 2A Widener between Buoys 13 and 15, 5A Widen Fishermans Channel and 3B Extend Fisher Island Turning Basin, and Deepen Channel (Any Depth)	$1,089,418

Article II. Artificial Reef Mitigation

Artificial reefs are often proposed for mitigating impacts to natural hardbottom habitats as a result of beach restoration (Lutz 1998). Mitigation reefs differ in several ways from traditional artificial reefs for fishing enhancement. Traditional artificial reefs are usually constructed offshore, are generally of high relief, are promoted as fishing destinations, and often utilize vessels or other non-natural substrate to offer divers an interesting alternative to natural reefs. In contrast, mitigation reefs should be designed to mimic the lost habitat as closely as possible in terms of relief and structural complexity. They should be placed in the same habitat depth zones as the impacted natural hardbottom/reef, and consumptive use of the reefs should be discouraged.

Artificial reefs have been used successfully for many years to mitigate impacts in sheltered waters (Duffy 1985) (Davis 1985) or in relatively deep water offshore (Mostkoff 1993). Reef deployments in shallow, open coastal areas present special challenges in the wave stability of materials and burial by sand movements in this very dynamic habitat. Palm Beach County has had considerable success with deploying shallow water artificial reefs as mitigation measures. The proposed design reflects the limitations on design and placement imposed by navigation regulations, liability issues, construction limitations, and stability concerns.

Section 2.01 Introduction

(a) Impacted Acreage and Associated Mitigation Requirements

Impacted artificial reef acreage for the recommended plan is 0.6 acres of low relief hardbottom and 2.7 acres of high relief hardbottom. Mitigation will be performed at a 2:1 ratio for the high relief hardbottom, resulting in 5.4 acres of mitigation and 1.3:1 ratio for low relief hardbottom, resulting in 0.8 acres of mitigation; therefore, a total of 6.2 acres of artificial reef is required. The ratios for reef mitigation were obtained by conducting two habitat assessments as recommended by the National Marine Fisheries Service and the US Fish and Wildlife Service. For the high relief hardbottom, NMFS and FWS requested that the Corps conduct a Habitat Equivalency Analysis (HEA) and for the low relief harbottom, NMFS and FWS requested that the Corps utilize the Joint State/Federal Mitigation Bank Review Team (MBRT) guidelines for temporal loss. The Corps concurred with this request. The HEA resulted in a mitigation ratio of 2:1 and the MBRT resulted in a mitigation ration of 1.3:1. NMFS and FWS have agreed that these values are acceptable.

(b) Possible Mitigation Sites

Mitigation reefs will be required in two different designs, to reflect the differences in the habitat structure of the two types of hardbottom/reef habitat to be impacted. The Corps reviewed four potential placement mitigation sites for hardbottom mitigation, two sites that are managed by Miami-Dade County and two sites that are currently unpermitted to receive mitigation reef materials.

Two types of mitigation reefs will be constructed; high relief high complexity (HRHC) reefs and low relief low complexity (LRLC) reefs. The HRHC reefs are intended to mitigate for impacts to high relief habitat and the LRLC reefs are intended to mitigate for impacts to lower relief reef. LRLC reefs will have a vertical relief of 1 to 2 feet and will be placed inshore of, and shallower than, HRHC reefs.

After reviewing the Miami-Dade county permitted sites, it was determined that one of the sites (DERM reef site A – north of the entrance channel) is too shallow to mimic the reef that is being impacted and has very little available space for reef construction. DERM reef site B – located to the south of the entrance channel has 58.3-acres of available space for reef creation. It already has some artificial reef located within the boundaries, which would allow for quicker colonization of artificial reef material, as well as allowing for easier monitoring since it is adjacent to a county mitigation site that is currently monitored. Water depths of this site are similar to the depths of high relief reefs being impacted by the proposed project (40 to 45 feet). The County has already completed the permitting process with the State of Florida for this artificial reef site.

The Corps reviewed two additional sites for placement of reef mitigation material. Both sites are located south of the entrance channel. The northernmost site is located north of DERM reef site B, and has shallower water depths (35 to 40 feet). The southern "L"-shaped site is directly adjacent to the DERM reef site B. However, it was determined that hardbottom communities are located within the proposed site, which would make using the site for mitigation construction difficult due to the requirement to avoid impacts to the existing resources within the site while constructing mitigation reefs.

In summary – the Corps proposes to use DERM reef site B and Corps site #1. DERM reef site A is too shallow for the proposed mitigation, and Corps site #2 has hardbottom communities located in the middle of it. If for some reason the DERM reef site is unavailable (Dade County denies the Corps usage of the site), the shorter part of the "L" at Corps site #2 may be used for mitigation reef construction.

Section 2.02 Alternative Artificial Reef Mitigation Plans

(a) Placement Method

Two alternatives for placement of the artificial reef were considered. One placement method would involve the use of divers to place the material. The second placement method would be to use a crane barge to place the material.

(i) Divers

Rock would be transferred from the port deepening location to the selected mitigation site on barges. Each rock would be lowered from the barge to the selected site below. A diver (or more than one diver) would be on the bottom and provide guidance for the rock placement, stacking the rock and ensuring that the rocks were securely placed on the bottom and stacked to a height necessary to properly mimic the functions of the impacted reef. While more successful at placing rock and guaranteeing the artificial reef is built to mimic the impacted reef, it is less efficient since it is limited by sea conditions, conditions on the bottom at the construction site (currents, visibility, water temperature) and the amount of time that an individual diver can spend on the bottom. Construction with Divers is typically more expensive than construction without divers.

(ii) Crane Barge

This construction technique is much the same as the with diver option, however, the reef is constructed only with the crane without diver involvement, which may prove more efficient due to not being limited by human SCUBA divers and the associated limitations.

(b) Construction Material

Both dredged rock and purchased quarry rock were considered for use as construction material.

(i) Dredged Rock

Rock blasted from the Harbor Deepening project is proposed to be used for construction of the mitigation reefs because the rock is native limestone, fossilized coral reef material and will quickly colonize with infaunal reef species who live within the rock structure of a coral reef.

(ii) Quarry Rock

Rock quarried from offsite must be of a material that can be utilized by infaunal reef species – so it must match the composition of the native reef material – which limits what rock can be used as a substrate. In south Florida reef environments the rock must be limestone. The rock must be of a large enough size and heavy enough to prevent movement of the reefs during storm events such as hurricanes.

(c) Alternative Plans

The combination of the two placement methods and the two construction materials leads to four alternative artificial reef mitigation Plans, as shown in Table 9.

Table 9: Alternative Artificial Reef Mitigation Plans

	Artifical Reef Placement Method	
Construction Material	*Diver*	*Crane Barge*
Dredged Material	Artifical Reef Mitigation Alternative 1	Artifical Reef Mitigation Alternative 2
Quarry Rock	Artifical Reef Mitigation Alternative 3	Artifical Reef Mitigation Alternative 4

Section 2.03 Expected Costs of Alternative Artificial Reef Mitigation Plans

(a) Cost of Material

There is no cost for dredged material obtained through harbor improvements. The cost of purchased quarry rock, the alternative to the dredged material, is shown in Table 10.

(b) Cost of Transportation and Placement of Material

Costs for artificial reef mitigation are shown in Table 10.

Table 10: Estimated Costs of Artificial Reef Mitigation Components

Expense	Cost/Project	AAE Cost/Project
Diver Placement	$1,586,258	$98,887
Crane Barge Placement	$893,873	$55,724
Dredged Material	$0	$0
Quarry Rock	$3,720,000	$231,905

(c) Estimated Cost of Each Artificial Reef Mitigation Alternative

Combining the component costs leads to an estimated cost for each Artificial Reef Mitigation Plan, shown in Table 11.

Table 11: Estimated Mitigation Expense by Alternative Artificial Reef Mitigation Plan

Artifical Reef Mitigation Alternative	Estimated Cost
1	$1,586,258
2	$893,873
3	$5,306,258
4	$4,613,873

Section 2.04 Artificial Reef Mitigation Benefits

(a) Effective Acreage

The immediate benefits of the newly constructed artificial reefs will be an estimated 20 percent of established reefs and will provide increasing benefits over time. The rate at which the benefits increase varies between low-relief and high-relief reefs, as shown in Table 12.

Table 12: Effective Acreage of Low- and High-Relief Mitigation

Effective Acreage Gained from Recovery of Low-Relief Artificial Reefs		
Project Year	**% Service Level***	**Effective Acreage**
1	20.00%	0.23
2	26.67%	0.30
3	33.33%	0.38
4	40.00%	0.45
5	46.67%	0.53
6	53.33%	0.60
7	60.00%	0.68
8	66.67%	0.75
9	73.33%	0.83
10	80.00%	0.90
11	86.67%	0.98
12	93.33%	1.05
13-50	100.00%	1.13
Effective Acreage Gained from Recovery of High-Relief Artificial Reefs		
Project Year	**% Service Level***	**Effective Acreage**
1	20.00%	1.01
2	22.67%	1.15
3	25.33%	1.28
4	28.00%	1.42
5	30.67%	1.56
6	33.33%	1.69
7	36.00%	1.83
8	38.67%	1.96
9	41.33%	2.10
10	44.00%	2.23
11	46.67%	2.37
12	49.33%	2.50
13	52.00%	2.64
14	54.67%	2.77
15	57.33%	2.91
16	60.00%	3.04
17	62.67%	3.18
18	65.33%	3.31
19	68.00%	3.45
20	70.67%	3.58
21	73.33%	3.72
22	76.00%	3.86
23	78.67%	3.99
24	81.33%	4.13
25	84.00%	4.26
26	86.67%	4.40
27	89.33%	4.53
28	92.00%	4.67
29	94.67%	4.80
30	97.33%	4.94
31-50	100.00%	5.07
*Source: Habitat Equivalency Analysis, Mitigation Plan, Appendix J - DEIS		

(b) Average Annual Equivalent AAE Acreage

AAE acreage refers to the average acreage of Artificial Reef expected to exist over the fifty years of the project. Because the reefs will not be immediately fully beneficial, AAE acreage is less than the total acreage experienced once the reefs are established. AAE for the Artificial Reef Mitigation is shown in Table 13.

Table 13: Total Effective AAE Artificial Reef Acreage

Total Effective AAE Low-Relief Acreage	1.01
Total Effective AAE High-Relief Acreage	3.81
Tota Effective AAE Acreage	4.82

Section 2.05 Comparing Artificial Reef Mitigation Plans

(a) AAE Cost per AAE Acre

Base year (discounted) costs of each alternative mitigation plan are annualized and compared to the respective AAE benefits. Dividing the AAE cost of a plan by its AAE acreage provides its AAE Cost/Acre benefits (see Table 14).

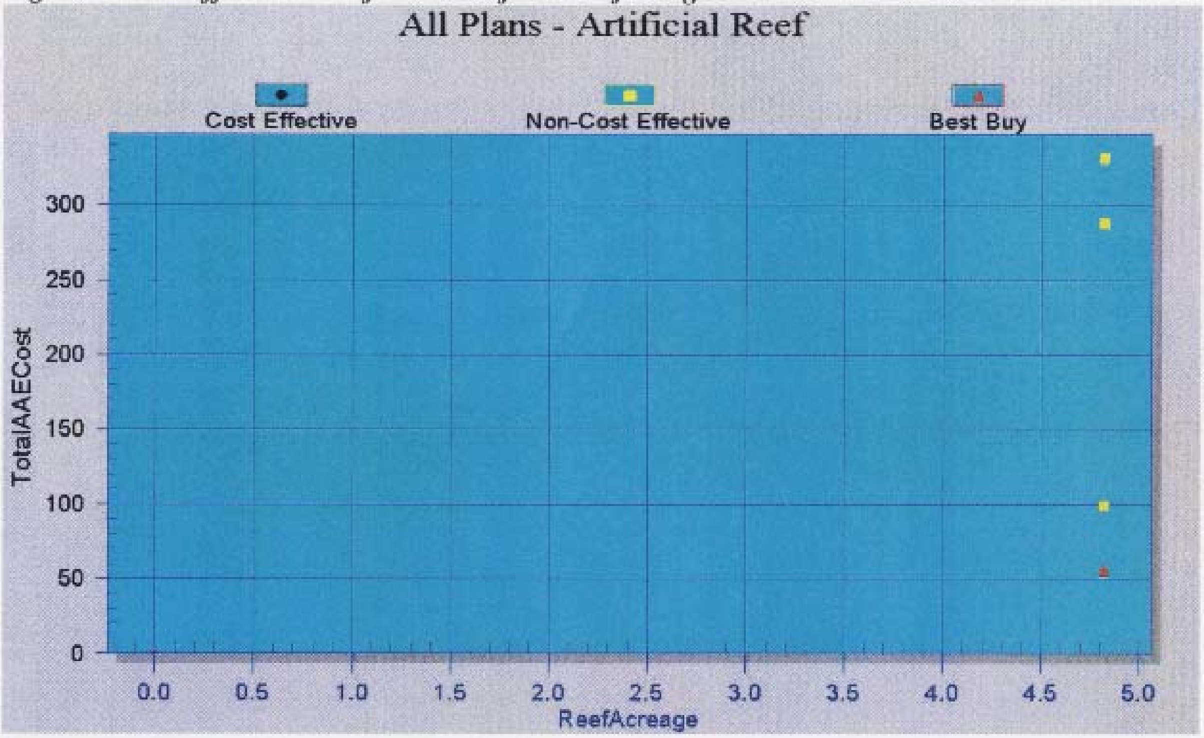
Table 14: AAE Cost per Acre of Artificial Reef Mitigation by Artificial Reef Mitigation Alternative Plan

Artifical Reef Mitigation Alternative	AAE Cost of Mitigation	AAE Benefits of Mitigation (acres)	AAE Cost/Acre
1	$98,887	4.82	$20,496
2	$55,724	4.82	$11,550
3	$330,792	4.82	$68,562
4	$287,629	4.82	$59,616

(b) Cost-Effective Artificial Reef Mitigation Plan

Table 14 shows that only Plan 2 provides a particular quantity of mitigation at the lowest price, the requirement for a cost-effective mitigation plan. This information can be seen graphically in Figure 3.

Figure 3: Cost Effectiveness of Each Artificial Reef Mitigation Plan



(c) Recommended Artificial Reef Mitigation Plan

As the sole cost-effective plan, Plan 2 is the Recommended Artificial Reef Mitigation Plan.

Section 2.06 Estimation of Artificial Reef Mitigation Costs for Alternative Project Plans

(a) Incremental Artificial Reef Mitigation Costs by Project Increment

Table 15 displays the estimated artificial reef mitigation cost by project increment (see Economics Appendix and Main Report for a discussion of project increments and alternative plans).

Table 15: Incremental Artificial Reef Mitigation Costs

Increment	Artificial Reef Mitigation Cost
1C Widen Entrance Channel, 2A Widener between Buoys 13 and 15, 5A Widen Fishermans Channel	$893,873
3B Extend Fisher Island Turning Basin	$0
Deepen System from 42 Feet to 43 Feet	$0
Deepen System from 43 Feet to 44 Feet	$0
Deepen System from 44 Feet to 45 Feet	$0
Deepen System from 45 Feet to 46 Feet	$0
Deepen System from 46 Feet to 47 Feet	$0
Deepen System from 47 Feet to 48 Feet	$0
Deepen System from 48 Feet to 49 Feet	$0
Deepen System from 49 Feet to 50 Feet	$0

(b) Artificial Reef Mitigation Costs by Alternative Plan

Table 16 displays the total estimated artificial reef mitigation costs for each alternative project plan.

Table 16: Artificial Reef Mitigation Costs by Alternative Project Plan

Project	Artificial Reef Mitigation Cost
Alternative Plan A: No Action	$0
Alternative Plan B: 1C Widen Entrance Channel, 2A Widener between Buoys 13 and 15, 5A Widen Fishermans Channel	$893,873
Alternative Plan C: 3B Extend Fisher Island Turning Basin	$0
Alternative Plan D: 1C Widen Entrance Channel, 2A Widener between Buoys 13 and 15, 5A Widen Fishermans Channel and 3B Extend Fisher Island Turning Basin	$893,873
Alternative Plan H: 1C Widen Entrance Channel, 2A Widener between Buoys 13 and 15, 5A Widen Fishermans Channel and 3B Extend Fisher Island Turning Basin, and Deepen Channel (Any Depth)	$893,873

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